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THE PHILIPPINE

JOURNAL OF SCIENCE

A. CHEMICAL AND GEOLOGICAL SCIENCES
AND THE INDUSTRIES

VOL. XIII MAY, 1918 No. 3

PRACTICAL OPERATION OF A PRODUCER-GAS POWER PLANT[1]

By FRANCISCO R. YCASIANO and FELIX V. VALENCIA

(*From the Bureau of Science, Manila*)

NINE TEXT FIGURES

Systematic investigations of the fuel resources of the Philippine Islands have shown that coal is of abundant occurrence.[2] Extensive studies of the calorific values, proximate analyses, physical characteristics, and steaming qualities of coal fuels have been made by Cox.[3] In opening up new Philippine coal mines,

[1] Received for publication February 26, 1918.

[2] Dalburg, F. A., Coal resources of the Philippines, *Min. Res. P. I. for 1911* (1912), 54–62; Coal mining in 1912, ibid. for 1912 (1913), 38–40.

Ferguson, H. G., Coal in the Cagayan Valley, *This Journal, Sec. A* (1908), 3, 535–537.

Ferguson, H. G., and Clark, R. N., Coal in the Cagayan Valley, *Min. Res. P. I. for 1909* (1910), 41–42.

Smith, W. D., The coal deposits of Batan Island, *Bull. P. I. Min. Bur.* (1905), 5, 1–56; The nonmetallic minerals, *Min. Res. P. I. for 1907* (1908), 11–12; The geology of the Compostela–Danao coal field, *This Journal, Sec. A* (1907), 2, 377–405; Philippine coal, *Min. Res. P. I. for 1909* (1910), 36–40; The coal resources of the Philippine Islands, ibid. for 1910 (1911), 37–56.

[3] Cox, Alvin J., Philippine coals and their gas-producing power, *This Journal* (1906), 1, 877–902; The proximate analysis of Philippine coals, ibid., *Sec. A* (1907), 2, 41–66; The relationship between the external appearance and the ash content of Philippine coal, ibid., *Sec. A* (1908), 3, 91–93; Philippine coals as fuel, ibid., *Sec. A* (1908), 301–355; Calorimetry, and the determination of the calorific value of Philippine and other coals from the results of proximate analysis, ibid., *Sec. A* (1909), 4, 171–204; Chemical and physical characteristics of Philippine coal, ibid., *Sec. A* (1912), 7, 1–18; The oxidation and deterioration of coal, ibid., *Sec. A* (1912), 7, 229–316.

the outcrop coal and the slack must be disposed of. It was believed that these would give excellent results in a producer-gas plant and if so would greatly help the industrial development of the country. Low-grade coals when converted into gas for internal-combustion engines give relatively high thermal efficiency. These facts led to a careful study of the various types of producer-gas apparatus and to installation of a suction producer-gas plant in the power house of the Bureau of Science for an additional power unit and for the trial of Philippine fuels in such a plant. In discussing these tests, many details are purposely included, because this is the only plant of its kind in the Philippines, and any data that may be obtained in operating it will serve as a guide in the operation of producer-gas plants that may be installed in the future.

SOURCES OF POWER IN THE PHILIPPINES

A comparison of different types of prime movers involves a consideration of many variable factors such as availability and transportation facility, quality and price of the fuel consumed, availability and price of general supplies, the use of the power, type of the unit, capital invested, interest, depreciation, and location of the machinery. When the power plant is large, the advantages of a given unit are frequently expressed only from the viewpoint of the fuel consumption cost per horsepower hour and include only a statement of the size and type of the prime mover. It is evident that such a statement is inaccurate, but on account of the large number of variables, it is impossible to make a general statement applicable to all types of prime movers included in a given class. The same variables render it possible to make only approximate calculations of power costs and the economy of the performance of various prime movers and, therefore, of the advantages or disadvantages of different types of engines.

As a source of energy in the Philippine Islands there are many waterfalls and streams of large capacity that are entirely undeveloped. At present prime movers are operated exclusively by (1) coal, (2) liquid fuel, or (3) miscellaneous fuels such as rice husks, sugar cane bagasse, saw mill waste, coconut shells or husks, etc. The general practice with regard to the use of these is as follows:

Coal.—The general practice is to fire coal directly under the boiler. The only instance in which it is converted first into producer gas for an internal combustion engine is in the plant of the Bureau of Science, which it is the purpose of this paper to

describe. No coal is converted into gas for use in boiler furnaces. A small quantity of briquetted coal is used from time to time in large plants. There is one cement rotary kiln that pulverizes coal for fire in powdered form. Pulverized coal is neither used in locomotives nor in any boiler installation in the Philippine Islands.

Liquid fuel.—Liquid fuel is commonly used for internal-combustion engines. There is no instance in which liquid fuel is fired under a boiler or converted into producer gas.

Miscellaneous fuels.—Rice husks are in extensive use in rice-mill furnaces with automatic stokers. Sugar cane bagasse is in general use in sugar-mill furnaces with or without automatic stokers. Saw dust, shavings, etc., are in general use in lumber-mill furnaces with automatic stokers. Coconut shells and husks are seldom used under boilers, but find extensive use for drying coconuts.

All of the fuels above enumerated offer possibilities of economical use in gas producers. However, they should not be substituted for coal or other satisfactory fuel, until it is shown by actual experiment that they cannot be used more economically for other purposes. For example, it might be more profitable to market portions of rice husks to be ground for use in mixed stock food than to burn them under a boiler.

DESCRIPTION OF BUREAU OF SCIENCE PRODUCER-GAS POWER PLANT

The gas producer of the Bureau of Science is of the up-draft suction type. It is designed, primarily, for lignite and subbituminous coal, which contain a high percentage of moisture and volatile hydrocarbons. This producer is especially suited for the use of Batan coal, which with most other Philippine coals falls into the above-mentioned class. However, with proper manipulations and regulations, the gas producer can be well used with any coal that does not cake sufficiently to obstruct the formation of gases. The plan of this producer-gas plant is shown in fig. 1.

Gas producer.—The Bureau of Science gas producer has a rated capacity of about 226 cubic meters per hour (8,000 cubic feet). The gas is used to run a four-stroke cycle 69- to 75-horsepower Otto gas engine direct coupled with a 50-kilowatt continuous-current dynamo, which supplies light and power to the Bureau of Science, the Philippine General Hospital, and some of the buildings of the University of the Philippines.

The producer proper, or gas generator, consists of an auto-

genously welded cylindrical iron shell, lined with asbestos fiber and fire brick. The contour, dimensions, and cross section of the producer are shown in fig. 2.

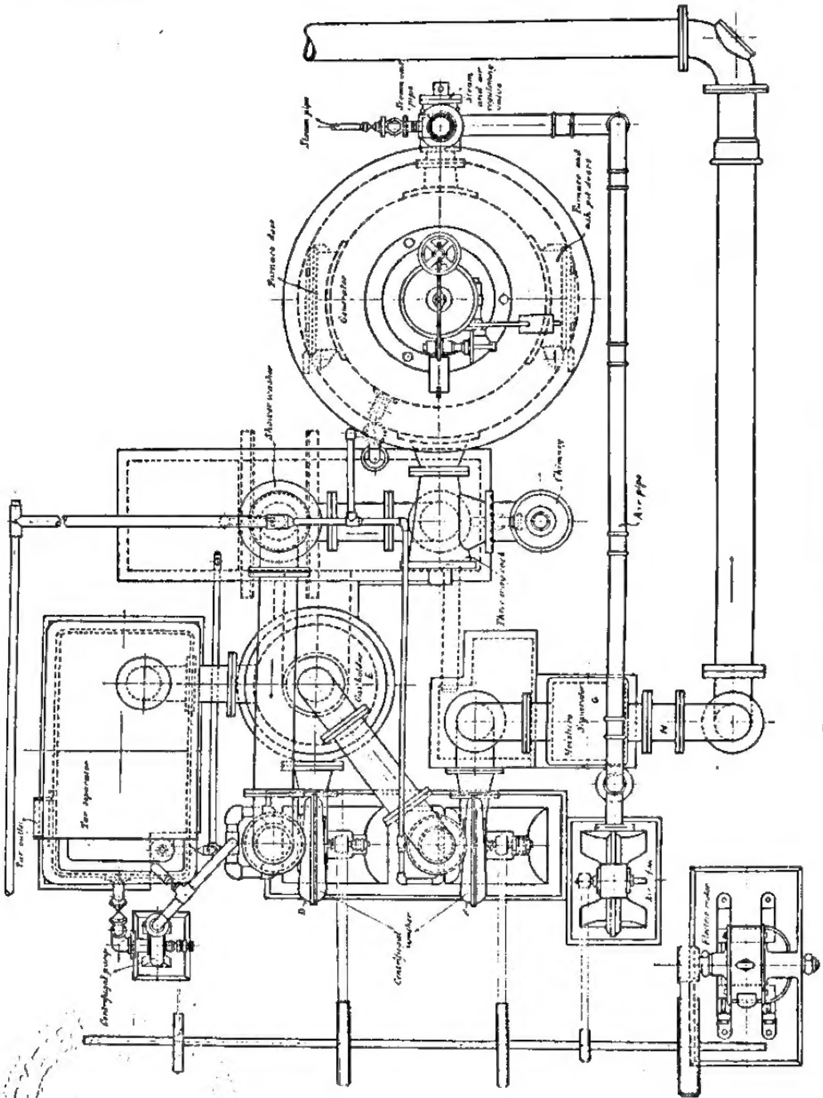

FIG. 1. Plan of the producer-gas plant.

Starting from the grate surface the inside contour of the producer is formed by a cylinder, *A*, 75 centimeters in diameter and 85 centimeters high, by an inverted truncated cone, *B*, 48.8 centimeters high and 130 and 75 centimeters in diameter at the top and bottom, respectively, and by another cylinder, *C*, 130 centimeters in diameter and 54.3 centimeters high. The upper part is as shown in the figure. The distance from the grate surface to the cover plate of the producer is 211 centimeters, and the

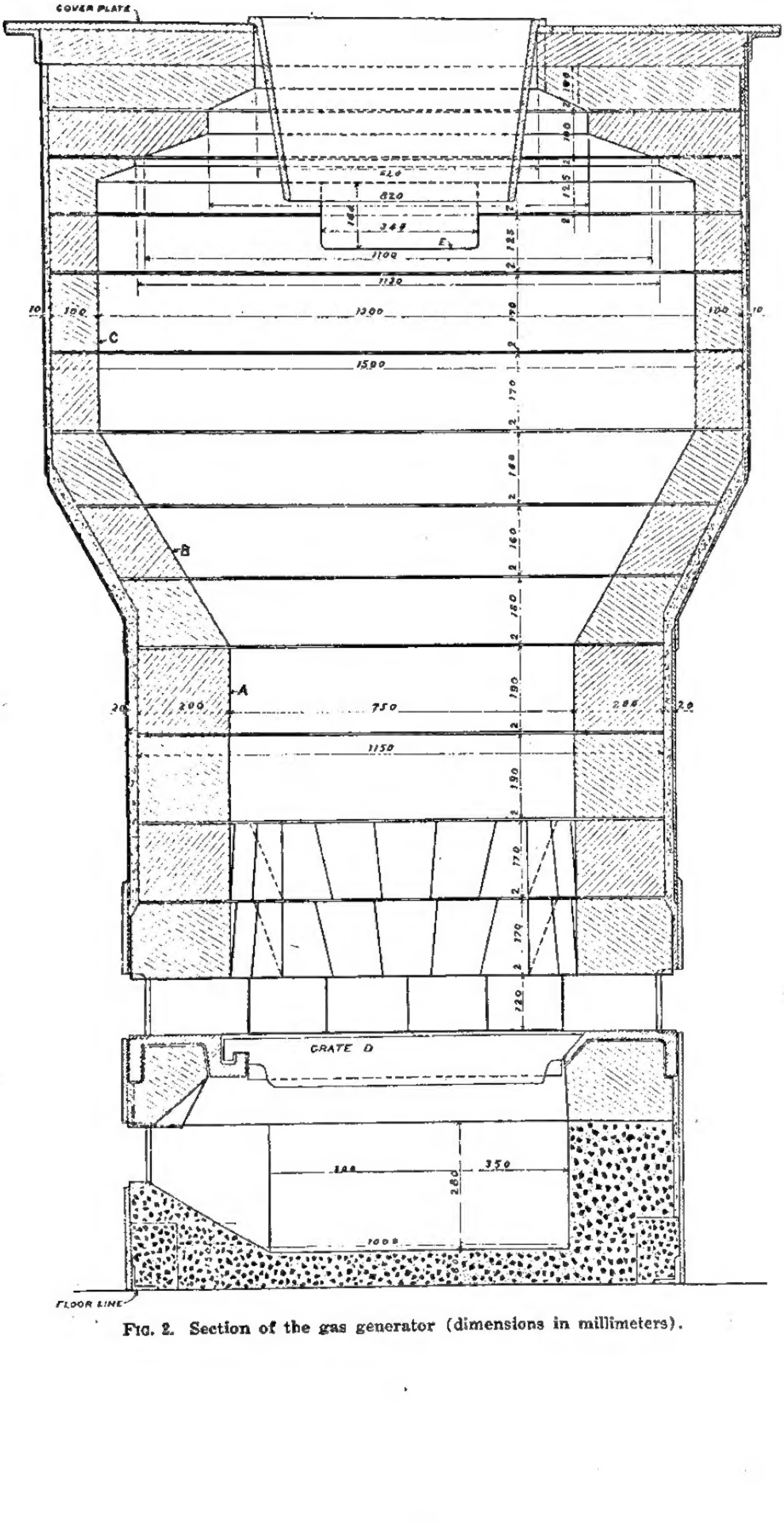

FIG. 2. Section of the gas generator (dimensions in millimeters).

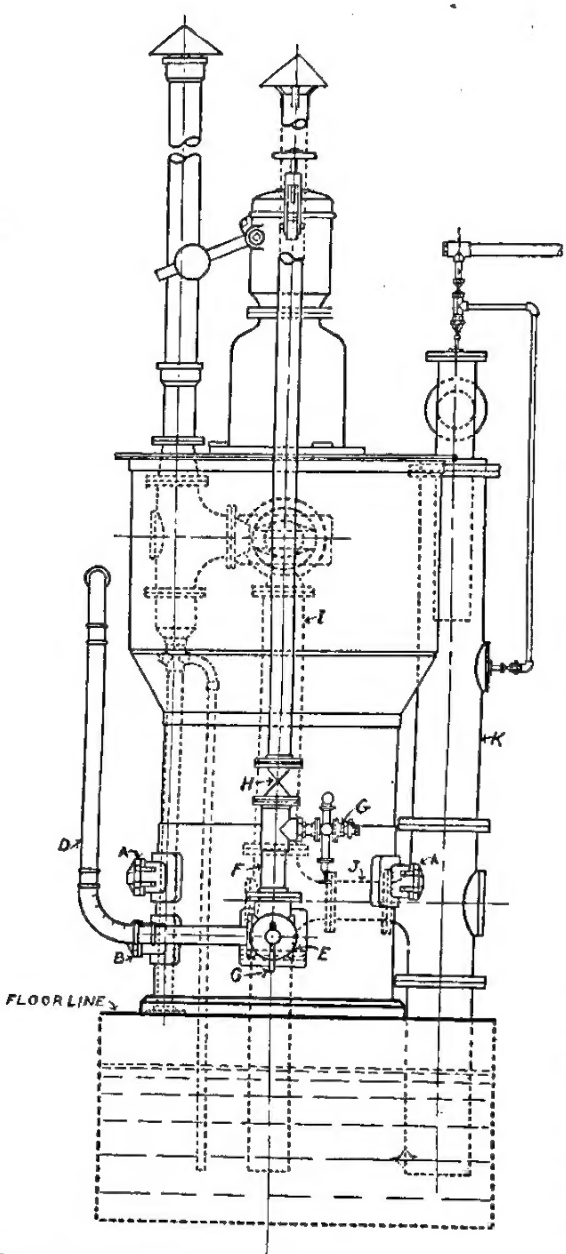

FIG. 3. Side elevation of the gas generator. The air and steam connection is fitted with a four-way cock *C*, by which connection can be made with the blast pipe *D*, with the opening *E* to the atmosphere, or with the pipe *F*, which carries a steam supply pipe *G*, with reducing valve, steam gauge, separator, and steam trap. The pipe *F* opens to the atmosphere by means of a regulating valve *H*.

height of the producer from the floor to the cover head, just beneath the charging platform, is 284 centimeters. The total height of the producer, including the hopper, is 460 centimeters.

Doors.—The producer is provided with two furnace doors (*A*, fig. 3), 50 centimeters by 12 centimeters, located at the level of the grate surface on opposite sides of the furnace. Directly below one of the furnace doors and having the same dimensions is the ash pit door (*B*).

Air and steam supply.—Air and steam are supplied through a connection in the ash pit wall on the side opposite the gas delivery pipe (fig. 3).

Water supply in the ash pit.—The ash pit can be flooded with water, up to a depth of 4 centimeters, if necessary (fig. 4).

Grate.—The grate consists of seventeen stationary bars shown at *D*, fig. 2.

The width of each bar is 15 millimeters, and the distance between any two consecutive bars is also 15 millimeters. The grate has a total area of 3,096 square centimeters, with a ratio between air space and grate surface of one to two.

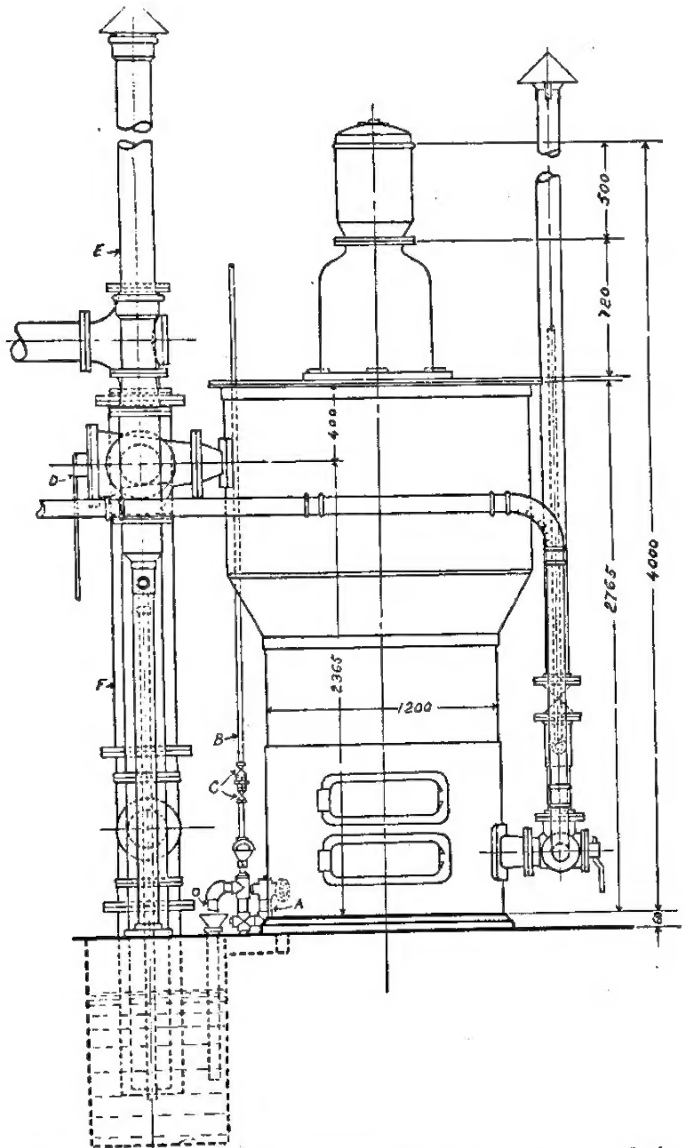

FIG. 4. Front elevation of the gas generator. For the purpose of flooding the ash pit, the water is supplied by the pipe *B*, in which the rate of flow may be regulated by the two valves *C*. The water supply pipe has an exit into the ash pit wall opposite the air intake and also through the *U*-pipe *A*, which constitutes the overflow *O* to the sewer.

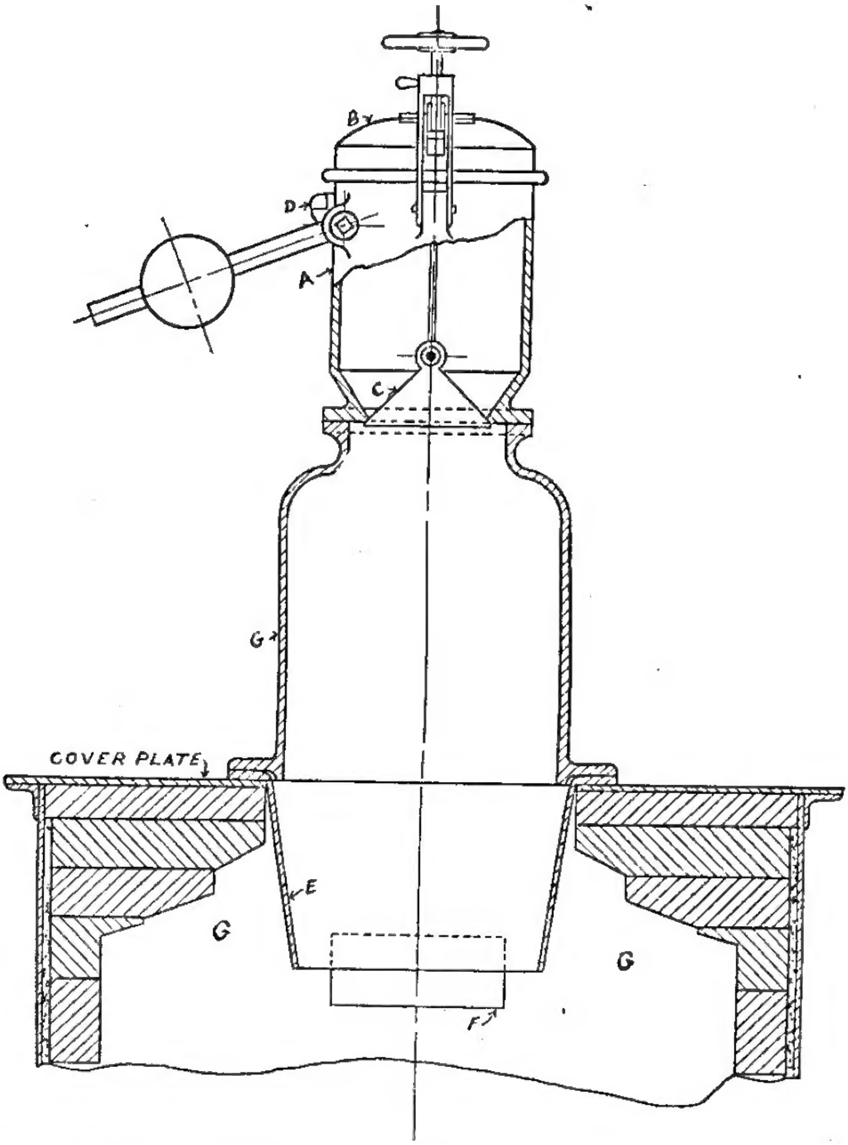

FIG. 5. Hopper. The essential parts of the charging hopper consist of the coal holder *A*, the cover *B*, and the valve *C*. The locking device *D* prevents the opening of the valve *C* when the cover *B* is open, and vice versa. This arrangement avoids the escape of gases when the producer is being charged. The extension of the hopper or the funnel *E* prevents filling the gas generator up to the cover plate, which would choke the gas outlet *F*. By means of this simple device, also, a supply of fuel sufficient for a considerable length of time is maintained in the chamber *G* in the top of the producer.

Hopper.—The coal is fed centrally into the producer by means of a charging hopper (fig. 5), which is bolted on the cover plate of the generator.

Gas outlet.—The gas outlet *E* (fig. 2) is a rectangular opening, 14.4 centimeters by 34.4 centimeters, controlled by the three-way cock *D* (fig. 4), which opens either to the chimney *E* or to the gas pipe *F*.

Cleaning machinery.—The vertical gas delivery pipe *I* (fig. 3), the inside diameter of which is 17.5 centimeters, is water-sealed at the lower end. The gas is forced through the pipe downward, and large quantities of dust, small particles of coal, and flaky ashes are removed. The direction of flow of the gas is changed abruptly by the short horizontal pipe *J*, 17.5 centimeters inside diameter, and by the vertical scrubber *K*, 30 centimeters in diameter. This scrubber, as is shown in the cross section (fig. 6), is provided with two spray nozzles of the umbrella type and with a water seal at the bottom. The water box is provided with an overflow to the sewer. The water spray from the nozzles meets the upward-going gas and removes most of any remaining dust or other residual solid matter in suspension. The water spray also serves the purposes of cooling the gas and of condensing the tar.

The gas, mixed with a certain amount of water that is fed and kept in circulation by a small pump, is next passed through the first centrifugal machine, revolving at a rate of about 2,800 per minute, where the heavy matter, consisting mostly of tar, is largely removed. In the machine the water is mixed intimately with the gas, and they are discharged together. The gas is separated by being collected in a vertical holder, and the water and impurities go into the separating tank. The tar floats on the water and runs through an opening in one side of the tank.

The holder, into which the gas is delivered by the first centrifuge, consists of a cylinder 65 centimeters in diameter by 110 centimeters in height, provided with an opening in one side to fit the discharge pipe. The center of this opening is located 17.5 centimeters above the bottom of the gas holder. A vertical pipe, open at both ends, passes through the bottom of the gas holder. The upper end of this pipe reaches slightly above the discharge pipe, while the lower is water-sealed. Another opening is in the cover of the gas holder and connects with the intake pipe of the second centrifuge.

On leaving the gas holder, the gas passes to the second centrifuge, where again it is mixed intimately with water, introduced as in the first centrifuge. This operation causes the further separation of residual tar in the gas.

The gas is then delivered under pressure to the condenser or moisture separator (fig. 7). This consists of seven perforated plates of equal dimensions, placed vertically on top of packed

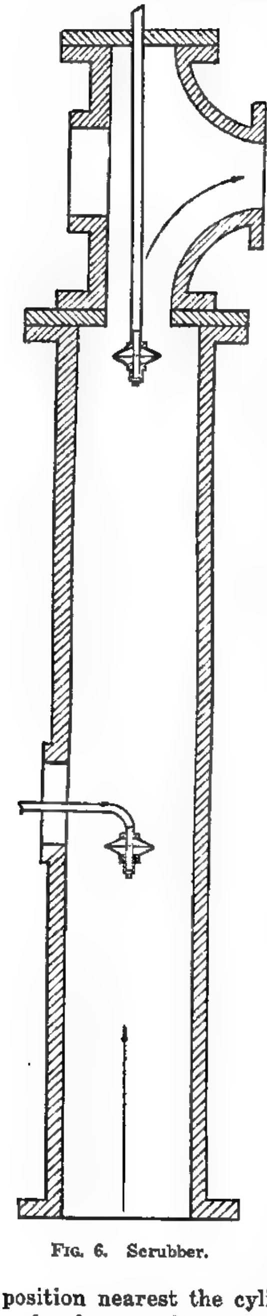

FIG. 6. Scrubber.

excelsior. The perforations are such as to facilitate aggregation of moisture particles, and the water that collects on the plates trickles into the excelsior. The apparatus is incased in a chamber, which has a removable cover and a water-sealed drain for discharging the water that is separated from the gas. After this treatment the gas is passed through a small gas holder. The diameter of the gas holder is greater than the supply pipe, and the pressure and velocity of the gas are considerably reduced in passing through it. This variation in pressure and velocity causes a further deposition of water, which from time to time is blown off through a drain cock in the bottom of the holder. Finally the gas is passed through the last separator, consisting of six baffles, constructed in such a way as to reverse the direction of the flow of the gas six times and practically to eliminate any moisture or tar that is still carried in the gas. This is the final purification, and the gas is delivered into the mixing chamber of the gas engine. The gas holder distributes the effect of the engine suction so as to produce a steady supply of gas to the engine.

Gas engine.—The action of the 4-stroke cycle engine driven by the gas is as follows:

1. Suction or first stroke, which begins as soon as the piston leaves its position nearest the cylinder head and which ends when it reaches its position nearest the crank. During this interval the suction valve is open, while the exhaust valve is closed.

2. Compression or second stroke, which begins as soon as the piston leaves its position nearest the crank and which ends when it reaches its position nearest the cylinder head. During this interval both the suction and exhaust valves are closed.

3. Working or third stroke, which begins when the explosive fuel is fired and as soon as the piston again leaves its position nearest the cylinder

head and which ends when it reaches its position nearest the crank. During this interval both the suction and exhaust valves are closed.

4. Exhaust or fourth stroke, which begins as soon as the piston again leaves its position nearest the crank and which ends when it reaches its position nearest the cylinder head. During this interval the suction valve is closed, while the exhaust valve is open.

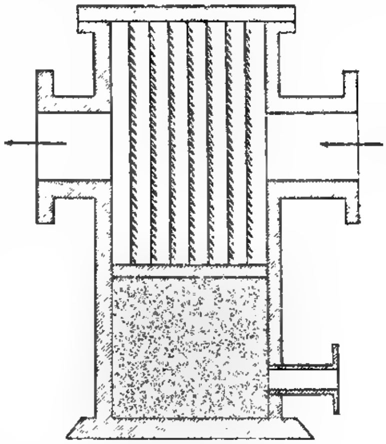

FIG. 7. Condenser.

Manner of governing the engine.—The governor of the engine belongs to the class that is called "precision" method of governing.

The mixture of gas and air has a constant proportion at all loads of the engine. This mixture of constant quality is throttled to suit the load by the action of a fly-ball governor, which shifts the position of the fulcrum about which the lever of the mixture inlet valve of the engine turns, thus increasing or decreasing the lift of the valve.

Dynamo.—The gas engine drives directly a 50-kilowatt compound-wound direct-current 110-volt dynamo manufactured in Germany.

This is wired in parallel with two 37.5-kilowatt compound-wound direct-current 110-volt dynamos made in the United States, which are driven directly by two high-speed steam engines provided with Rite's inertia governors. Fig. 8 gives the details of connections of the dynamos to the main switchboard.

Auxiliary motors.—The power plant of the Bureau of Science is run continuously and gives an available electric power supply, at any time, of 110 volts direct current. In choosing the type of motors to run the auxiliary machinery of the producer-gas power plant, it was decided that electric motors were most suitable. A 9-horsepower motor drives the air blower, the centrifuges, and the water pump, and a 2-horsepower motor drives the air compressor, which is used only to fill the compressed-air tank for starting the gas engine.

METHOD OF OPERATION

Starting the producer.—When the producer is empty, ascertain first that the grate is clean and the wall free of clinkers. Open the three-way cock in the gas flue to the chimney. Build a good wood fire on the grate, close the doors, and start the air blower. Feed enough coal through the charging hopper, about 30 kilograms at intervals of about ten minutes, but be careful

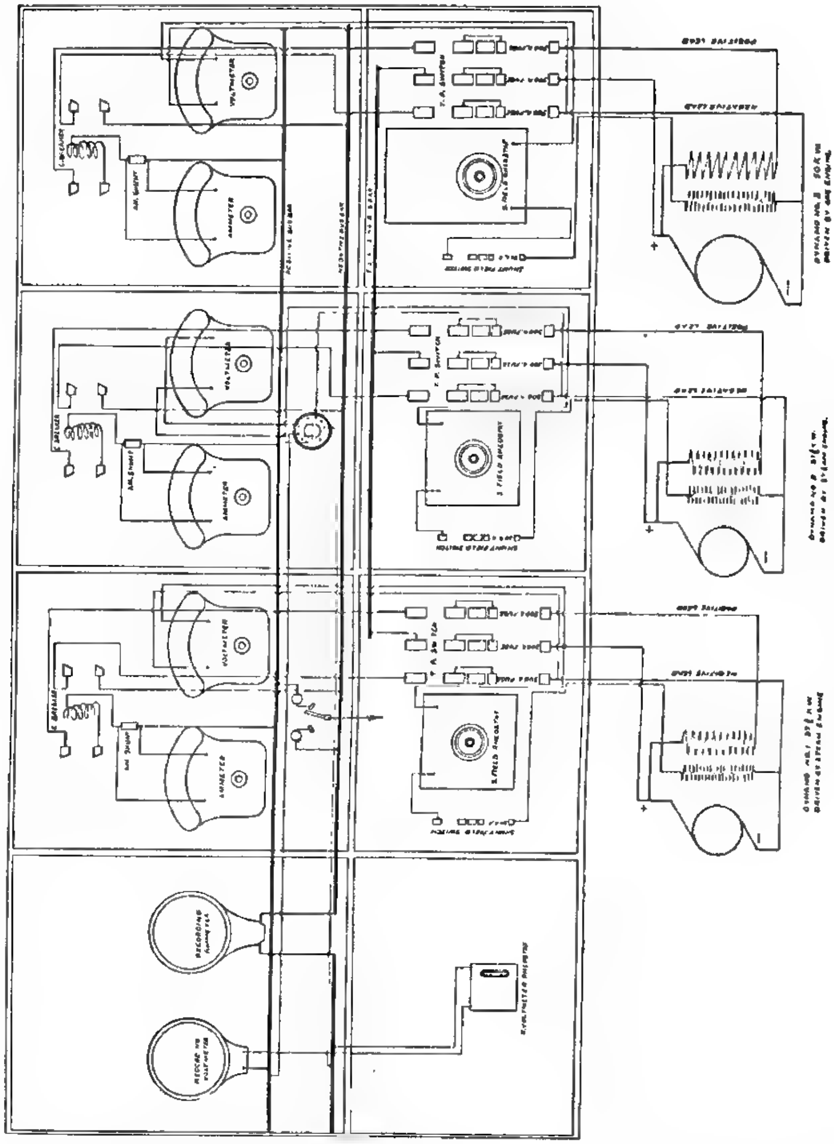

FIG. 8. Switchboard connections.

not to smother the fire. See that the gas purge valve near the exhaust of the engine is open to the atmosphere. Test the gas in the burner connected to the three-way cock; if it is ignited, stop the blower, turn the four-way cock to admit air directly from the atmosphere, and put the three-way cock in the gas flue in position to discharge gas into the delivery pipe. Never stand directly in front of the air intake of the producer, as back firing

may occur during these operations. Introduce water in the ash pit at the rate of about 6 liters per hour; open the water supply of the spray nozzles in the scrubber, the discharge valve of the water pump, and its relief valve located in the discharge pipe; and open also the water supply of centrifuge 2 and start the motor that drives the centrifuges and the water pump. See that this motor is clean and that there is sufficient oil in all bearings. Close the relief of the water pump. The gas is still discharging into the atmosphere, but is ready for use in the gas engine.

When the plant is in operation, the gas producer must be charged up to a permanent level for each particular fuel. The charging must be done at sufficient intervals to keep the quality of the gas practically constant. An interval of every two hours, which takes about ten minutes of the time of one fireman, is usually sufficient.

The starting of the producer is simpler if a fire has been previously built. There is no need of using the air blower; all that is required is to clean the fire and draw the ashes and clinkers out, to open all the necessary valves, and to start the motor that drives the centrifuges and the pump for circulating water. Within ten minutes or less the quality of the gas is good enough to start the engine.

Starting the gas engine.—The gas engine is started by means of compressed air with a pressure of about 12 kilograms per square centimeter.

When the engine is in operation, the time of explosion and the air throttle valve should be regulated to suit the amount and composition of the gas. All moving parts that require lubrication should receive the proper amount of oil. The water in the cooling jacket should not exceed a temperature of about 60° C., and its temperature should be maintained as uniformly as possible.

The proper amount and the kind of oil to be used in an internal combustion engine are very essential in its successful operation. The rate of feed of oil in the most important moving parts of the gas engine in the Bureau of Science is as follows: Eleven to 14 drops per minute in the cylinder; 15 to 20 drops per minute in the piston pin; and 60 to 90 drops per minute in the crank pin. The cylinder oil should be used only once. If the rate of feed of this oil is properly controlled, there will be very little waste. Surplus oil is not only wasted, but forms carbon deposits on piston, valves, and cylinder head, which should be avoided as much as possible.

Stopping the operation.—In stopping the operation of the producer-gas plant, the load of the gas engine should be gradually decreased before disconnecting it completely.

The purge valve should be opened, and the gas throttle of the engine should be closed. Immediately after this operation the motor that drives the auxiliary cleaning machinery should be stopped, the three-way cock in the discharge pipe of the producer left in communication with the chimney, and all water supply stopped. The valve for admitting air in the ash pit should be entirely closed, if the producer is to stand idle less than sixteen hours; otherwise the air intake must be regulated to give just sufficient draft to keep the fire alive. All these manipulations should be performed as quickly as possible, so there is time to return to the gas engine before it slows down too much. The engine should be stopped at the right position for starting. This can be easily done with practice.

RECORDS OF TESTS

The tests were made under actual running conditions without interfering with the regular supply of light and power. The results obtained have been duplicated day after day in ordinary practice. No special preparations were made to obtain exceptionally high records, because we believe that a plant should be judged on what it can ordinarily perform rather than on what it can perform under the most favorable conditions.

Fuel used.—The fuels used were Batan and Fushon coals; the former is black lignite mined in the Philippines, and the latter is Manchurian bituminous coal. The analyses of these fuels are shown in Table I.

TABLE I.—*Analyses of Batan and Fushon coal.*[a]

	Per cent.
Batan coal:	
Moisture	14.63
Volatile combustible matter	39.09
Fixed carbon	38.73
Ash	7.55
Total	100.00
Total calories	5,150
Available calories	4,753
Fushon coal:	
Moisture	4.66
Volatile combustible matter	39.94
Fixed carbon	48.01
Ash	7.40
Total	100.00
Sulphur (separately determined)	0.89
Coking quality	semicoking
Color of ash	grayish white
Total calories	7,133
Available calories	6,633

[a] Analyzed by A. S. Argüelles, inorganic chemist, Bureau of Science.

The Batan coal used in firing the producer had been stored for several years.[4]

The size of coal used varied from a powder to about 4 centimeters, and the Fushon coal contained an especially high percentage of slack. Preliminary trials were carried on for several weeks, during which time care was used to determine the influence of different sizes of fuel. The uniformity of size has little influence, and now the coal is used as delivered, either directly or after being screened, for charging the producer. Large lumps are broken into pieces about 3.5 centimeters in diameter.

The data given in Tables II and III are the averages of twenty tests ranging from six to fifty-five hours in duration. In each test readings were taken every fifteen minutes, except during the night shifts. The fuel used in tests 1 to 16 was Batan coal, and in tests 17 to 20 it was Fushon coal.

Table IV shows the results of tests for the entire power plant. These results were computed from data shown in Tables II and III.

Table V gives the analyses of intake and exhaust gases of the gas engine. The numbers of analyses correspond to those shown in the previous tables.

Analyses marked "A" and "B" show very low content of carbon monoxide. These were made on producer gas from a Chinese coal. The coal caked very considerably, and the engine was run only for about four hours, when the producer was clogged, stopping the formation of gas. An attempt was made to over-

[4] It is interesting to compare its analysis with that made by Cox [*This Journal, Sec. A* (1907), 2, 52] of a fresh sample from the same coal seam secured many years before, whose results are as follows:

Batan Island, Bett's.

	Official method.	Smoking-off method.
	Per cent.	*Per cent.*
Water	15.41	55.41
	15.42	15.42
Volatile combustible	41.74	39.46
	41.83	39.46
Fixed carbon	39.05	41.02
	38.97	41.00
Ash	3.80	4.11
	3.78	4.12
Total sulphur	0.22	

come this difficulty by mixing different quantities of ashes with the coal to prevent caking, but it was unsuccessful.

In one case the hydrogen content of the gas reached 20.2 per cent. This had a marked effect on the gas engine, causing pounding when it was loaded to about 50 per cent of the rated capacity. Under continuous heavy load the engine does not operate well when the hydrogen in the gas exceeds 14 per cent.

The lower calorific values of the gas per cubic meter as consumed are given in Table VI. The test numbers correspond to the numbers in the previous tables. A Junker gas calorimeter was used in making the determinations. The results were calculated by the formula:[5]

$$C=\frac{1000\ W\ (Tow\text{-}Tiw)\ +\ K\ (Tiw\text{-}Tg)\ +\ K'\ (Teg-Tiw)}{G},$$

where C=calories per cubic meter.

G=liters of gas consumed as registered in the meter.

Tow=temperature of outlet water.

Tiw=temperature of inlet water.

Tg=temperature of gas at meter.

Teg=temperature of escaping gases.

W=water passed through the calorimeter in liters.

K,K'=constant calculated by Bates from the specific heats of the average quality of gases, equal to 0.0089 and 0.470 calorie, respectively.

[5] Latta, Nisbet, American Producer Gas Practice and Industrial Gas Engineering (1910), 451.

15644——2

TABLE II.—*Gas-generator tests.*

Test No.	Duration of test.	Coal.	Weight of coal.	Water. For ash pit and scrubber.	Water. For centrifuge No. 2.	Water. Total.	Auxiliary motor. Amperes.	Auxiliary motor. Volts.	Auxiliary motor. Kilowatt hours.	Water gauge. Ash pit.	Water gauge. Producer outlet.	Water gauge. Condenser outlet.	Temperature. Separating tank.	Temperature. Producer outlet.	Temperature. Condenser outlet.	Ash.	Clinker.
	Hrs.		*Kilos.*	*cu. m.*	*cu. m.*	*cu. m.*				*mm.*	*mm.*	*mm.*	*°C.*	*°C.*	*°C.*	*Kilos.*	*Kilos.*
1	6	Batan	296	10.4	6.3	16.7			32.6	10.7	71.1	400.6		114.6		31	5.5
2	8	do	317	11.83	3.35	15.28	42.9	106.2	36.4	11.6	39.0	394.0	42.8	93.5	33.3	52	9.0
3	6.25	do	328	11.35	2.15	13.5	44.3	106.1	29.37	11.0	47.0	395.0	41.5	101.5	33.4	32	8.5
4	8	do	396	15.35	2.65	18.0	45.4	110.5	40.1	14.9	49.6	389.0	43.9	108.1	35.09	27	8.0
5	8	do	396	8.00	2.90	10.9	46.5	106.2	39.44	31.0	70.0	375.0	42.1	121.0	35.0	23	6.0
6	5	do	242	4.0	1.8	6.0	46.5	105.3	24.45	20.0	67.0	361.0	40.5	133.3		23	12.0
7	8	do	391	8.2	3.2	11.4	48.7	106.0	41.28	7.9	62.3	388.0		108.0		14.5	2.5
8	8	do	389	9.85	3.4	13.25			37.6	5.3	45.0	399.0		138.0		28	15.0
9	8	do	416	8.4	3.3	11.7	46.0	106.6	39.2	13.7	30.7	407.0		121.0		29	10.0
10	6	do	323	7.0	2.5	9.5	44.5		28.32	20.0	37.0	404.0		113.0		27	11.0
11	8	do	400	7.8	3.1	10.9	46.5		39.44	22.8	40.4	396.0		103.6		30	13.0
12	8	do	380	7.8	3.3	11.1	46.9		39.76	16.0	22.6	408.0		96.4		50	8.0
13	8	do	428	7.6	3.4	11.0	44.8		36.10	7.5	11.5	412.0		98.5		48	7.0
14	8	do	417	8.7	3.1	11.8	47.0		39.85	4.6	12.0	416.0		100.0		45	9.0
15	7	do	310	7.1	10.6	17.7	57.1	107.4	42.91	4.88	39.8	398.2	47.8	67.8	32.8		
16	49.5	do	2,321	56.43	10.5	75.93	53.0	105.1	275.73	9.09	43.04	394.3	48.9	118.09	37.45	110	51.0
17	7	Fushon	210	6.40	7.5	13.90	48.2	105.2	35.50	76.3	85.8	332.0	50.7	530÷	40.1	50	26.0
18	8	do	222	11.7	3.0	14.70	54.0	104.0	44.80	43.1	61.3	359.0	61.4	530+	47.2	41	42.0
19	8	do	220	14.0	6.8	20.80	47.0	105.5	39.60	21.1	40.8	348.0	63.4	500	47.9	60	23.0
20	55	do	1,955	60.55	22.5	83.05	50.4	105.0	291.06	45.5	60.4	335.5	58.9	530+	45.3		

TABLE III.—*Data sheet of gas-engine tests.*

Test No.	Duration of test.	Kilowatt hour.	Volts.	Amperes.	Water.			Temperature.				
									Water jacket.			
										Outlet.		
					Cylinder jacket.	Cylinder head jacket.	Exhaust pipe jacket.	Room.	Intake.	Cylinder.	Cylinder head.	Exhaust pipe.
	Hrs.	*M.*			*cu. m.*	*cu. m.*	*cu. m.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*
1	6	205	-------	-------	6.3	12.2	4.8	-------	-------	-------	-------	-------
2	8	278	110.6	313	8.5	14.05	3.25	33.4	25.1	49.2	40.0	47.7
3	6.25	238	110.4	341.5	6.5	11.35	2.4	33.8	24.9	45.4	40.4	49.0
4	8	298	110.4	327.6	8.4	17.05	2.6	34.1	25.0	46.0	38.7	52.5
5	8	320.8	110.9	320.8	9.5	14.8	2.8	33.6	25.0	42.8	39.9	47.5
6	5	210	110.0	316.9	5.0	9.7	1.7	33.3	25.0	48.0	40.1	50.2
7	8	312	110.8	344.8	7.55	14.9	4.25	-------	-------	-------	-------	-------
8	8	301	110.2	355.2	7.4	15.0	2.95	-------	-------	-------	-------	-------
9	8	303	110.3	328.1	8.2	15.5	5.2	-------	-------	-------	-------	-------
10	6	233	111.1	337.9	6.0	11.3	3.2	-------	-------	-------	-------	-------
11	8	320	109.9	366.7	11.9	16.8	2.8	-------	-------	-------	-------	-------
12	8	287	111.0	310.1	10.4	18.5	3.9	-------	-------	-------	-------	-------
13	8	250	110.7	272.1	12.3	17.3	4.5	-------	-------	-------	-------	-------
14	8	275	110.7	301.6	9.1	18.5	4.4	-------	-------	-------	-------	-------
15	7	236	110.4	282.3	8.9	18.8	3.4	-------	28.4	45.0	40.6	48.0
16	49.5	1,607	109.7	290.6	57.0	105.0	24.7	-------	29.7	42.0	46.6	44.2
17	7	255	109.5	320.9	7.4	17.0	4.0	-------	31.0	49.1	41.6	42.5
18	8	270	109.2	293.7	7.7	19.9	4.9	-------	31.0	49.6	42.6	43.0
19	8	236	109.4	268.6	9.6	19.5	5.6	-------	31.0	49.0	40.8	42.5
20	55	1,816	109.9	312.9	80.1	136.6	33.5	-------	31.0	49.4	41.5	42.3

TABLE IV.—*Results of tests of entire power plant.*

Test No.	Duration.	Fuel.	Total.					
			Coal consumed.	Power generated.	Power consumed by auxiliary machinery.	Net power generated.	Water used in generator and for cleaning the gases.	Water for cooling the engine.
	Hrs.		*Kilos.*	*k. w. h.*	*k. w. h.*	*k. w. h.*	*cu. m.*	*cu. m.*
1	6	Batan coal	296	205	32.60	172.40	16.70	23.30
2	8	do	317	278	36.40	241.60	15.28	25.80
3	6.25	do	328	238	29.37	208.63	13.50	20.25
4	8	do	396	298	40.10	257.90	18.00	28.05
5	8	do	396	320.8	39.44	281.36	10.90	27.10
6	5	do	242	210	24.45	185.55	6.00	16.40
7	8	do	391	312	41.28	270.72	11.40	26.70
8	8	do	389	301	37.60	263.40	13.25	25.35
9	8	do	416	303	39.20	263.80	11.70	28.90
10	6	do	323	233	28.32	204.68	9.50	20.50
11	8	do	400	320	39.44	280.56	10.90	31.50
12	8	do	380	287	39.76	247.24	11.10	32.80
13	8	do	428	250	36.10	213.90	11.00	34.10
14	8	do	417	275	39.85	235.15	11.80	32.00
15	7	do	301	236	42.91	194.09	17.70	31.10
16	49.5	do	2,321	1,607	275.73	1,331.27	75.93	166.70
17	7	Fushon coal	210	255	35.50	219.50	16.60	28.40
18	8	do	222	270	44.80	225.20	16.40	32.50
19	8	do	220	236	39.60	196.40	20.80	34.70
20	55.0	do	1,955	1,816	291.06	1,524.94	83.05	250.20

TABLE IV.—*Results of tests of entire power plant*—Continued.

Test No.	Fuel.	Hourly quantities.					
		Coal consumed.	Power generated.	Power consumed by auxiliary machinery.	Net power generated.	Water used in generator and for cleaning the gases.	Water for cooling the engine.
		Kilos.	*k. w. h.*	*k. w. h.*	*k. w. h.*	*cu. m.*	*cu. m.*
1	Batan coal	49.33	34.16	5.43	28.73	2.783	3.883
2	do	39.62	34.75	4.55	30.20	1.910	3.225
3	do	52.48	38.08	4.69	33.38	2.160	3.240
4	do	49.50	37.25	5.01	32.23	2.250	3.506
5	do	49.50	40.10	4.93	35.17	1.362	3.387
6	do	48.40	42.00	4.89	37.11	1.200	3.280
7	do	48.87	39.00	5.16	33.84	1.425	3.337
8	do	48.62	37.62	4.70	32.92	1.656	3.165
9	do	52.00	37.87	4.90	32.97	1.462	3.612
10	do	53.93	38.83	4.72	34.11	1.585	3.416
11	do	50.00	40.00	4.93	35.07	1.362	3.937
12	do	47.50	35.87	4.97	30.90	1.387	4.100
13	do	53.50	31.25	4.51	26.73	1.375	4.262
14	do	52.12	34.37	4.98	30.39	1.475	4.000
15	do	43.00	33.71	6.13	27.58	2.528	4.442
16	do	46.88	32.46	5.57	26.89	1.533	3.367
17	Fushon coal	30.00	36.43	5.07	31.36	2.371	4.057
18	do	27.75	33.75	5.60	28.15	2.050	4.062
19	do	27.50	29.50	4.95	24.55	2.600	4.337
20	do	35.54	33.01	5.29	27.72	1.510	4.549

TABLE IV.—*Results of tests of entire power plant*—Continued.

Test No.	Fuel.	Economic quantities.					
		Coal per kilowatt hour generated.	Coal per net kilowatt hour.	Water for generator and for cleaning gases per kilo of coal.	Water for cooling the engine per kilowatt hour generated.	Water for cooling the engine per net kilowatt hour.	Total water used per net kilowatt hour.
		Kilos.	*Kilos.*	*cu. m.*	*cu. m.*	*cu. m.*	*cu. m.*
1	Batan coal	1.443	1.716	0.0564	0.1131	0.1351	0.2320
2	......do	1.140	1.312	0.0482	0.0928	0.1067	0.1700
3	......do	1.378	1.572	0.0400	0.0850	0.0975	0.1617
4	......do	1.328	1.535	0.0454	0.0941	0.1087	0.1785
5	......do	1.234	1.407	0.0275	0.0844	0.0963	0.1350
6	......do	1.152	1.304	0.0247	0.0780	0.0883	0.1207
7	......do	1.253	1.444	0.0291	0.0855	0.0986	0.1407
8	......do	1.292	1.476	0.0366	0.0812	0.0962	0.1465
9	......do	1.372	1.576	0.0283	0.0953	0.1095	0.1501
10	......do	1.382	1.578	0.0299	0.0879	0.1001	0.1465
11	......do	1.250	1.461	0.0272	0.0984	0.1122	0.1511
12	......do	1.324	1.536	0.0292	0.1108	0.1326	0.1775
13	......do	1.711	1.953	0.0257	0.1364	0.1594	5.2108
14	......do	1.516	1.773	0.0282	0.1163	0.1360	0.1862
15	......do	1.275	1.550	0.0588	0.1317	0.1602	0.2514
16	......do	1.444	1.743	0.0327	0.1161	0.1402	0.1972
17	Fushon coal	0.827	0.957	0.0790	0.1113	0.1293	0.2050
18	......do	0.822	1.011	0.0738	0.1203	0.1443	0.2171
19	......do	0.932	1.120	0.0900	0.1470	0.1766	0.2325
20	......do	1.076	1.282	0.0424	0.1372	0.1647	0.2119

TABLE V.—*Analyses of producer and exhaust gases.*[a]

Test No.	Kind of gas.	Coal.	Hour.	Carbon dioxide (CO_2).	Oxygen (O_2).	Carbon monoxide (CO).	Methane (CH_4).	Hydrogen (H_2).	Nitrogen (N_2).
				P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	Intake	Batan	9 a. m.	3.6	2.1	24.8	1.7	7.5	60.3
	Exhaust	do	10 a. m.	15.1	2.9	....	....	....	82.0
	Intake	do	12 m.	5.7	1.3	26.1	2.6	8.3	56.0
	Exhaust	do	2.30 p. m.	14.3	1.5	....	....	....	84.2
	Intake	do	2.30 p. m.	5.3	0.2	26.8	2.8	9.5	55.4
4	do	do	12 m.	3.6	0.3	27.7	3.2	10.9	54.3
	do	do	2 p. m.	4.2	0.5	28.4	2.0	8.1	56.8
	Exhaust	do	2 p. m.	15.7	0.6	....	....	....	83.7
5	Intake	do	10 a. m.	3.7	0.8	28.6	2.3	11.6	53.0
	Exhaust	do	10 a. m.	15.8	3.2	....	....	....	81.0
7	Intake	do	8 a. m.	4.9	0.7	26.0	2.7	9.2	56.5
	Exhaust	do	12 m.	15.6	2.1	2.0	....	....	80.3
8	Intake	do	12 m.	4.3	1.0	27.4	2.7	10.6	54.0
	Exhaust	do	2.15 p. m.	16.6	1.6	....	....	....	81.8
9	Intake	do	8 a. m.	4.3	5.9	20.0	0.6	2.2	67.0
	do	do	12 m.	4.4	1.6	25.6	3.0	13.1	52.3
10	do	do	12 m.	4.6	2.2	26.5	2.5	7.9	56.3
	Exhaust	do	12 m.	14.8	1.2	....	....	....	84.0
12	Intake	do	8.50 a. m.	4.1	....	31.1	2.6	10.0	52.2
	do	do	4 p. m.	3.7	....	30.3	1.9	10.4	53.7
13	do	do	11 a. m.	5.1	0.2	28.4	2.8	10.9	52.6
	do	do	1.45 p. m.	4.7	1.9	27.0	2.6	14.6	49.2
14	do	do	8.45 a. m.	5.0	0.3	33.8	2.6	5.5	52.8
	do	do	3.20 p. m.	4.5	0.4	28.2	3.1	12.2	51.6
17	do	Fushon	11 a. m.	10.3	0.2	23.4	2.3	19.5	44.3
18	do	do	8 a. m.	4.7	1.0	23.5	1.9	13.1	55.8
19	do	do	11 a. m.	4.1	0.6	23.9	1.3	20.2	49.9
A	do	China	2.30 p. m.	7.7	2.5	23.1	2.3	13.2	51.2
B	do	do	11.30 a. m.	6.3	3.3	18.6	2.7	13.3	55.8

[a] Analyzed by A. S. Argüelles, chemist, Bureau of Science.

TABLE VI.—*Calorific values of producer gas.*

Test No.	Coal used in gas generator.	Time of test.	Lower calories per cubic meter of gas under ordinary temperature and barometric pressure.
8	Batan	1.25-1.29 p. m.	1,373.4
	do	1.48-1.52 p. m.	1,409.9
	do	3.17-3.21 p. m.	1,407.2
9	do	8.52-8.56 p. m.	958.3
	do	9.24-9.28 a. m.	1,190.6
	do	9.50-9.54 a. m.	1,226.9
	do	10.20-10.24 a. m.	1,347.4
	do	10.50-10.54 a. m.	1,362.8
	do	11.20-11.24 a. m.	1,418.1
	do	2.19-2.23 p. m.	1,106.0
	do	2.52-2.56 p. m.	1,222.6
10	do	10.06-10.10 a. m.	1,473.4
	do	11.06-11.10 a. m.	1,362.2
	do	11.33-11.37 a. m.	1,348.7
11	do	10.23-10.27 a. m.	1,223.7
	do	11.35-11.39 a. m.	1,298.6
	do	2.04-2.08 p. m.	1,396.2
	do	3.06-3.10 p. m.	1,333.0
13	do	2.55-2.59 p. m.	1,352.5
14	do	11.20-11.24 a. m.	1,376.9
18	Fushon	11.30-11.35 a. m.	1,264.5
	do	1.30-1.35 p. m.	1,565.6
	do	1.49-1.54 p. m.	1,055.9
	do	2.32-2.37 p. m.	1,089.0

Since the preceding tests were made, Uling, Yoshinotani, Hokoku, and Chaoko Chwang coals, a mixture of coconut husks and shells, and copra cake have been successfully used to operate the producer.

The results obtained from the mixture of coconut husks and shells and from copra cake bear a direct important relation to the improvement that can be introduced in the process of drying copra and in the use of these fuels in the copra-oil mills. The results are given in Table VII.

TABLE VII.—*Results of tests of mixture of 1 volume of coconut husks to 2 volumes of shells and of copra cake alone used as fuel in a producer-gas generator.*

Test No.	Duration of run.	Fuel.	Lower calorific value of fuel.	Lower calorific value of producer gas per cubic meter under ordinary pressure and temperature.	Total fuel.	Total net kilowatt hours generated.	Fuel per net kilowatt hour.
	Hours.				*Kilos.*		*Kilos.*
1	6	Mixture of husk and shell 1:2 by volume.	Husk=3,781; Shell=4,060	1047.1	589.0	154.0	3.80
2	7				684.0	208.0	3.26
3	8				714.0	236.5	3.19
4	8				677.5	237.0	2.85
5	10	Copra cake	3,855	1455.6	996.0	308.6	3.22

The mixture of husks and shells gave the best result in test 4, which can be accounted as due to the experience acquired by the operators in firing the fuel before this test was performed. The amount of husks and shells on hand was not sufficient to make a series of tests of varying proportions in order to establish beyond doubt the most economical mixture of husks and shells for this particular producer. However, in the preliminary trials this was done during short intervals, and it has shown that pure husks can be burned in this producer only when the load is very light, because its design is adapted for relatively dense fuels. The shells when used alone behaved much like lignite with regard to their load-carrying capacity. The standard charge adopted in the tests was one volume of husks to two of shells, and this mixture was capable of responding to the maximum load of the engine. The fuel was fired as received—the shells in hemispheres and each husk in from four to six pieces. The depth of the fuel was maintained at the full capacity of

the producer. The tests have shown conclusively that mixture of husks and shells can be successfully burned in a suction producer. The design of a producer in which husks are to be used should provide a volume in proportion to the quantity of husks to be used in the mixture; the less this amount, the smaller the producer. When shells alone are to be burned, the producer will conform very closely in design to one for lignite.

Walker[6] has shown the average weights of husks and shells from 1,000 seashore and 1,000 inland coconuts to be 800 and 286.5 grams, respectively. Based on these figures and on the consumption of 2.85 kilograms of fuel per net kilowatt hour as recorded in test 4, the use of the shells alone from ten nuts to produce 1 kilowatt hour is a very conservative estimate. Therefore a copra plant that uses 10,000 nuts in ten hours' operation will be capable of generating 1,000 kilowatt hours during the same period or 100 kilowatts in one hour. This means that there is a possibility of designing a copra drier that could be either gas or electrically heated, the temperature control of which would be ideal. Besides, there would probably be surplus power for coir or other industries.

On account of the excessive rise in the price of coal copra cake was tried in order to obtain sufficient data to enable us to compare its value with coal. The ash of copra cake is useful as a fertilizer, and its value for such purpose should be deducted from the cost of copra cake. Tables VII and VIII give, respectively, the results of the use of copra cake as fuel and its analysis.

TABLE VIII.—*Analysis of copra cake.*[a]

Oil in cake (per cent)	10.86
Moisture (per cent)	11.00
Ash (per cent)	4.70
Potassium oxide (K_2O) in ash (per cent)	22.51
Loss on ignition of ash (per cent)	29.02
Lower calorific value of copra cake (calories)	3,855
Higher calorific value (calories)	4,350

[a] Analyzed by Messrs. Wells, Peña, and Argüelles, chemists, Bureau of Science.

The results of commercial tests of Uling coal mined in Cebu, P. I., are shown in Table IX.

Table X gives the cost data of the producer-gas plant under discussion.

[6] *This Journal* (1906), 1, 79.

TABLE IX.—*Results of commercial tests of Uling coal (Cebu, P. I.) in the producer-gas power plant of the Bureau of Science.*

Test number.	Duration of test.	Total fuel used.	Total ash and refuse.	Total electric energy generated, net.	Coal per net k. w. h.	Calorific value of the coal.		Higher calorific value of the gas.		Thermal efficiency of the entire power plant (including dynamo).		Load factor.	Remarks.
						Higher.	Lower.	B. t. u. per cu. ft.	Calories per cu. m.	Based on higher calorific value.	Based on lower calorific value.		
	Hours.	*Kilos.*	*Kilos.*	*k. w. h.*	*Kilos.*	*Calories.*	*Calories.*			*Per cent.*	*Per cent.*	*Per cent.*	
1	11	535.2	112.9	330.5	1.61								The coal was thoroughly washed and stored to dry before firing.
2	15.5	717.9	101.0	509.0	1.39								It produced some hard clinkers.
3	15.5	721.5	133.5	460.4	1.56								It can be successfully used in the gas producer.
Average	14	658.2	115.8	433.3	1.52	6,736	6,256	138	1,230	8.40	9.04	70.20	

TABLE X.—*Cost of installation and operation.*

[Net capacity of the plant, 44 kilowatts.]

	Pesos.
Total investment, including transportation, foundation, and installation	17,945.00
Fixed charges per annum:	
Interest at 8 per cent	1,435.60
Depreciation at 7 per cent	1,256.15
Maintenance and repairs 3 per cent	538.35
Total	3,230.10
Operating cost (8 hours' daily run):	
Fuel at 8 pesos per ton	927.28
Wages of one power engineer and one fireman	1,825.00
Oil and waste	91.25
Total	2,843.53
Total kilowatt hours for 300 days	74,400
Fixed charges per net kilowatt hour	0.0434
Operating cost per net kilowatt hour	0.0382
Total cost of operation per net kilowatt hour	0.0816
Operating cost (24 hours' daily run), 300 days:	
Fuel at 8 pesos per ton	2,781.84
Wages of three power engineers and three firemen	3,475.00
Oil and waste	205.30
Total	6,462.14
Fixed charges per net kilowatt hour	0.0144
Operating cost per net kilowatt hour	0.0289
Total cost of operation per net kilowatt hour	0.0433

In the calculations in Table X the number of days in a year was taken as three hundred. Both the maintenance and repairs were included in the fixed charges as so much percentage of the capital invested. The water used for cooling the engine and cleaning the gases was not included in the calculation—its cost per kilowatt hour is insignificant.

SPECIAL DIFFICULTIES AND MEANS OF AVOIDING THEM

Clinkers.—The Batan coal, which contains a high percentage of moisture, was formerly used in the producer without any endothermic agent except the natural moisture. At that time the longest safe run was sixteen hours. This was due to the formation of clinkers on the wall of the producer and to a thin but

tough layer of clinker that continuously deposited on the surface of the grate. The removal of this deposit was extremely difficult. The heat evolved by the coal was so intense that it caused the grate bars to burn out. To counteract the excessive heat of the fire bed and the formation of clinkers, water was introduced into the ash pit. This had to be stopped at once, as it produced pounding of the engine caused by premature ignition, on account of the sudden formation of a large percentage of hydrogen in the gas fuel.

The logical means to overcome the excessive heat and the consequent formation of a large amount of clinker and destruction of the grate bars was to use in the fire bed another endothermic agent that would not liberate hydrogen. This could have been obtained by diverting part of the exhaust gases of the engine into the fire bed of the producer. However, the engine exhaust is situated at a considerable distance from the producer, and there was not at hand the necessary piping, so that the introduction of water in the ash pit was tried again and this time was very successful. It was known from the start that Batan coal contains a very high percentage of moisture, which liberates a corresponding high percentage of hydrogen in the gas. The problem was then reduced to establishing the safe limit of water evaporated in the ash pit. For this purpose the small water-supply pipe leading to the ash pit was provided with two valves in series, the lower one was regulated to suit the necessary evaporation and the upper one was left wide open; the lower valve once regulated was left in its position, and the upper one was used only as a service valve for starting or stopping the water supply. Through these valves a very small amount of water was introduced into the ash pit at first. Very slowly this was increased, and at the same time the effect produced in the engine by the gas explosion was carefully noted. It was found by experiment that the evaporation of 6 liters of water per hour was sufficient to protect the grate and the wall of the producer without causing pounding of the engine, even when under full load.

The Fushon coal does not form bad clinkers as long as a small amount of steam is blown into the fire bed with air. The steam is obtained from the boiler that supplies steam to the laboratories. In independent installations the necessary steam can be obtained from a small boiler heated by the gas-engine exhaust. Usually steam is not necessary when the ash pit is kept flooded

with water, which evolves sufficient vapor to protect the grate and the wall of the producer.

Güldner[7] says:

> An ample supply of steam to the generator is of advantage from a practical standpoint, since it tends to decrease clinkering and to prevent the rapid burning away of lining and grates. Too high a percentage of hydrogen in the gas, however, leads to heavy explosions in the cylinder of the engine. Only a few engines can stand from 7 to 10% of hydrogen in the mixture, i. e., from 15 to 20% in the producer gas; in most of them, under continued heavy load, a troublesome knocking appears as soon as the gas contains more than 10% of hydrogen. The composition of the producer gas should therefore not be made entirely dependent upon the efficiency of the gasification process.

Disturbing the fire.—When there is necessity of performing an operation that will disturb the fire, if Batan coal is being used, the ash pit should be dried first, as the glowing particles of coal and hot ashes falling in the water will cause a large liberation of hydrogen and consequent pounding of the engine. Once the ash pit is dry, the necessary stoking should be done as quickly as possible so as not to leave the grate unprotected by the cooling action of the water vapor for a long time.

After finishing the operation of stoking, the water supply of the ash pit should be immediately opened after removing any hot refuse consisting of ashes and small particles of coal and broken clinkers that have fallen through the grate. When Fushon coal is used, these precautions are not necessary.

Cleaning the fire.—In cleaning the fire when Batan coal was used, there was no appreciable alteration in the action of the gas engine, even when the period of cleaning lasted as long as twenty minutes. Unfortunately this was not the case with Fushon coal, for, after three minutes of stoking, the gas engine usually slowed down and stopped. The cause of it was found to be due to the formation of a gas very rich in hydrocarbons resulting in a mixture too rich for ignition. Therefore the air throttle valve of the engine was widely opened during the process of stoking, and the gas valve was left at about 20 per cent of its full opening. At these positions of the valves the engine worked well, and the period of stoking could be prolonged even to twenty minutes, affording ample time thoroughly to clean the fire. A few minutes after cleaning the fire the gas and air throttle valves should be returned to their original positions.

[7] Güldner, Hugo, The Design and Construction of Internal-Combustion Engines. Translation by Herman Diederichs (1910), 521.

Clogging of the gas flue and the delivery pipe.—When the producer is not fully charged there is considerable deposition of dust and small particles of impurities in the gas flue and in the delivery pipe, necessitating a cleaning about every two weeks. Under this condition the distance from the hopper valve to the surface of the fuel bed is considerable. The gas flue, which is under suction all the time, is located between these two levels. Naturally when the coal is fed into the producer through the hopper valve, it falls in front of the gas flue, and small particles of coal and dust are sucked in and deposited in the flue and in the delivery pipes. Running the producer full prevents the serious clogging of the pipes, and a more uniform gas is obtained.

As another means of avoiding clogging of the flue and the delivery pipe a hole was made in the center of the three-way cock fitted with a removable plug. Through this hole a scraping rod can be inserted, even when the producer is in operation, to remove any deposit in the flue. The vertical and the short horizontal delivery pipes were also provided each with a nozzle for water supply, which can be kept in operation when a long run of several months without stop is desired.

Centrifugal separators.—The circulating water in centrifuge 1 was found to contain ammonia from the gas and tar. The ammonia present attacked the brass blades of the centrifuge to such an extent that complete renewal within about four weeks was necessary. Iron blades were substituted, and from that time no more trouble from this source was experienced.

Hopper.—The hopper used for coal and lignite (fig. 6) was found to be unsuited for the mixture of coconut husks and shells due to its small opening and capacity. A special hopper for this fuel was designed, as shown in fig. 9.

CARE AND MAINTENANCE

The care necessary in a producer-gas plant is less than that required in a steam plant of the same capacity. In the producer plant there is no boiler. This obviates the need of the continuous attention of at least one fireman, who is required to throw small amounts of coal into the boiler furnace at short intervals, distributing it evenly over the grate surface in order to attain high efficiency in operation. The only attention required in such a producer-gas plant as that at the Bureau of Science is to charge the gas producer full or nearly so every one or two hours when coal is the fuel, which takes about ten minutes of the fireman's time, and to draw out the ashes and clinkers about every ten hours, or requiring in each operation about fifteen minutes.

Sometimes it is necessary to break the clinkers on the grate surface, which is done by passing the hook bar underneath between the grate bars. This operation takes about five minutes every three hours, according to the condition of the fire bed. Add to this the time required for poking the fuel when the fire has a tendency to hang, say four minutes about every four hours, we have a total of less than about five hours in twenty-four of time expended. Or the total time of actual stoking necessary in a 69- to 75-horsepower producer is only about 20 per cent of that required in a boiler of about the same horsepower rating.

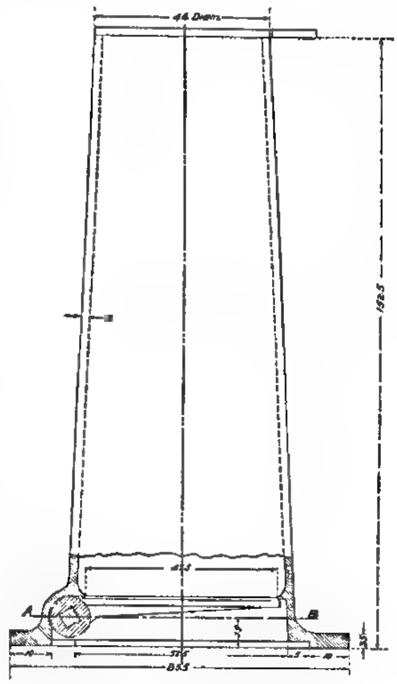

FIG. 9. Special hopper for coconut husks and shells.

Besides the fireman, there is usually an operating engineer, as in the steam plants, but his time is not wholly taken up, since there are no steam boilers, steam pipes, or auxiliaries under high steam pressure. The routine duty of the engineer in a producer-gas plant is to see that the engine and auxiliaries are properly lubricated, that the water jacket has a uniform correct temperature, and that the quality of the gas is practically constant and of the highest obtainable calorific value. The operating engineer must also know how to judge whether the fire bed needs stoking or not without actually seeing it. He should make a periodical five-minute inspection at intervals depending on the skill and trustworthiness of the fireman. The rest of the time of the engineer can be given to other work.

It must not be implied that what has been enumerated above constitutes the only care necessary in a producer-gas plant. The purifying apparatus, piping, and auxiliaries must be cleaned about once a month, depending on the quality of the fuel; the valves of the engine must be also cleaned and, if necessary, ground from time to time; the gas engine must be thoroughly cleaned about once every month, depending on the number of hours of use and the purity of the gas. The producer can be

successfully run for many months without any trouble if it is properly handled, but it is advisable to empty it for inspection whenever the gas engine is stopped for general cleaning and to overhaul and clean it thoroughly if necessary. Still the necessary work in a producer-gas plant is far less than that required in cleaning the boiler, steam engine, and auxiliaries in a steam plant of similar capacity.

CONCLUSIONS

1. The operation of the producer-gas plant at the Bureau of Science is very simple, and almost any solid combustible may be used. So long as the engine is properly lubricated and cooled, the necessary attendance is practically reduced to charging the producer from every one hour to two hours and to cleaning the fire once or twice a day.

2. The producer-gas plant of the Bureau of Science is very reliable. It has been in daily operation for nearly five years, and since 1914 has been operated continuously for twenty-four hours each day, except for the necessary short stops for cleaning at intervals of from two weeks to two months. The brick lining of the producer has not been renewed; it has required small repairs only from time to time, and there is no evidence of its being badly deteriorated.

3. At the Bureau of Science the parallel operation of the 50-kilowatt dynamo driven by the producer-gas engine and the two 37.5-kilowatt dynamos coupled to the steam engines is very satisfactory. Both the gas and steam engines respond quickly to any change in load.

4. With the same fuel, the load necessary to generate one kilowatt hour in the Bureau of Science producer-gas plant is only about a third of that required to produce the same energy in a steam plant of approximately the same capacity.

5. All the fuels experimented with were satisfactory, but the advantages in regard to minimum attendance of the producer and simplicity of operation are in favor of them in the following order, namely, Batan (Philippine) coal, Hokoku (Japanese) coal, coconut shells, Fushon (Manchurian) coal, Uling (Philippine) coal, copra cake, Chaoco Chwang (Chinese) coal, and Yoshinotani (Japanese) coal.

6. The results of the tests of coconut shells and husks described in this paper indicate the possibility of using the producer gas or the electric energy derived from it for copra drying and for driving machinery in connection with the copra industry and for extracting husk fibers.

7. A producer-gas plant of the type used in the Bureau of Science is well adapted for, and can be exceedingly economically and satisfactorily operated in, the Philippine Islands. The continuity of its operation is assured, since the producer can burn not only Philippine fuels, but also any one of several imported coals that are available in the local market.

8. A producer-gas plant solves the problem of smoke nuisance.

9. The installation of producer-gas plants in the Philippine Islands will greatly help in the conservation of fuels and in solving the fuel problem.

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ILLUSTRATIONS

TEXT FIGURES

FIG. 1. Plan of the producer-gas plant.

2. Section of the gas generator (dimensions in millimeters).
3. Side elevation of the gas generator. The air and steam connection is fitted with a four-way cock *C*, by which connection can be made with the blast pipe *D*, with the opening *E* to the atmosphere, or with the pipe *F*, which carries a steam supply pipe *G*, with reducing valve, steam gauge, separator, and steam trap. The pipe *F* opens to the atmosphere by means of a regulating valve *H*.
4. Front elevation of the gas generator. For the purpose of flooding the ash pit, the water is supplied by the pipe *B*, in which the rate of flow may be regulated by the two valves *C*. The water supply pipe has an exit into the ash pit wall opposite the air intake and also through the *U*-pipe *A*, which constitutes the overflow *O* to the sewer.
5. Hopper. The essential parts of the charging hopper consist of the coal holder *A*, the cover *B*, and the valve *C*. The locking device *D* prevents the opening of the valve *C* when the cover *B* is open, and vice versa. This arrangement avoids the escape of gases when the producer is being charged. The extension of the hopper or of the funnel *E* prevents filling the gas generator up to the cover plate, which would choke the gas outlet *F*. By means of this simple device, also, a supply of fuel sufficient for a considerable length of time is maintained in the chamber *G* in the top of the producer.
6. Scrubber.
7. Condenser.
8. Switchboard connections.
9. Special hopper for coconut husks and shells.

FERTILIZER EXPERIMENTS WITH SUGAR CANE [1]

By José Mirasol y Jison
(From the College of Agriculture, Los Baños)

TWO TEXT FIGURES

Sugar cane is an exhausting crop on any soil. According to Maxwell,[2] a ton of sugar, when the trash of the cane is returned to the soil, removes from it 12.7 pounds (5.77 kilograms) of nitrogen, 35.3 pounds (16.45 kilograms) of potash, and 8.2 pounds (3.72 kilograms) of phosphoric acid. An 8-ton sugar crop per hectare would then remove 46.2 kilograms of nitrogen, 131.5 kilograms of potash (K_2O), and 29.8 kilograms of phosphoric acid (P_2O_5). The common practice in the Philippines is to plant cane after cane on the same field without restoring the plant food removed by the crops. The world's experience is that no one crop can be continuously and profitably grown on the same unfertilized soil, no matter how rich it was at the beginning. In Queensland, Maxwell analyzed some virgin soils and some that were continually cropped with cane. A comparison of his results showed a loss of 31 per cent of nitrogen, 42.2 per cent of potash, and 37.2 per cent of lime. Considering that the sugar produced in the Philippines in one year (1916) amounted to 374,000 tons from 179,761 hectares of land,[3] it is apparent that the question of maintaining the fertility of our sugar lands is of national importance.

The use of commercial fertilizers for cane was recently introduced into the Philippines. But the failure of some farmers in their attempt to increase the yield of cane by the use of commercial fertilizers has created an atmosphere of prejudice against their use among local cane growers. This condition is rather unhappy. As a general proposition there is nothing wrong about the use of commercial fertilizers. The failure of the farmers who tried to use them was due to a lack of information regarding the manurial requirements of their soils, to be

[1] Portion of graduation thesis for the degree of Master of Science, No. 3. Received for publication January 31, 1918.

[2] Sugar Cane. Published by German Kali Works.

[3] This figure was obtained from the Bureau of Agriculture booth stand at the February, 1917, Philippine Carnival.

obtained by carefully controlled tests and trials. To fill this deficiency and to develop a system of fertilization trials that could be followed elsewhere in the Islands, I undertook the present experiments.

METHOD AND TIME OF APPLICATION OF FERTILIZERS

Deerr,[4] speaking of the proper application of various artificial manures, says that readily soluble forms of fertilizers such as nitrate of soda and ammonium salts should be applied as top dressings. Organic forms of nitrogen requiring the action of soil organisms must be buried 5 or 6 centimeters in the soil. Superphosphates are applied either as top dressings or are buried at a slight depth. Basic slag and mineral phosphates must be incorporated in the soil. Potash salts should be also incorporated.

Most investigators agree that the best time for application is during the early growth of the cane. They differ as to the advisability of a second application. Watt's [5] experiments in the Leeward Islands led him to conclude that the one-application system is better. In Hawaii, however, the application of nitrate of soda at the second growing season is found beneficial. The two-time application is practiced in Barbados.

THE AMOUNT OF FERTILIZERS TO BE APPLIED

For the stiff clay of Demerara, Harrison [6] recommended the application of 50 pounds (54.24 kilograms per hectare) of nitrogen in the form of sulphate of ammonia, with 500 to 600 pounds of ground phosphate slag per acre (543.12 to 654.48 kilograms per hectare). In Barbados the planters use from 40 to 80 pounds of nitrogen in the form of nitrate of soda and ammonium sulphate, combined (43.44 to 86.88 kilograms per hectare), and 80 to 100 pounds (87 to 109 kilograms per hectare) of sulphate of potash per acre. In Louisiana the amount of fertilizer used is from 400 to 700 pounds per acre (436.32 to 872.64 kilograms per hectare). In Hawaii as much as 2,400 kilograms of fertilizers are applied per hectare.[7] The amount of fertilizers to be applied is a question that should be determined for each locality.

[4] Deerr, Noel, Cane Sugar (1911).
[5] Ibid.
[6] Sugar Cane. Published by German Kali Works.
[7] Deerr, Noel, Cane Sugar (1911).

PRESENT EXPERIMENTS

The present experiments were carried out on a clay-loam soil from which a crop of sweet potato had been harvested. The land was first thoroughly plowed, and then fifteen plots of 450 square meters each were laid off. The Los Baños white cane was used. It had been previously found that this variety of cane would yield 5.86 tons of 96° sugar per hectare.[8] The seeds were all selected, as to size, from a field of plant cane. The rows were 1.5 meters apart, and the seeds were laid 25 centimeters from end to end at the bottom of furrows 30 centimeters deep. Planting began May 8, 1916, and was finished May 10, 1916. On May 16 the canes were nearly all above the ground. On July 15 the stools in each plot were counted. The percentage of success in each plot is shown in Table I.

TABLE I.—*Los Baños white cane planted in a clay-loam soil.*

Plot.	Seeds planted.	Stools counted.	Success.	Plot.	Seeds planted.	Stools counted.	Success.
			P. ct.				*P. ct.*
1	600	483	80	9	600	507	84
2	600	472	79	10	600	529	88
3	600	405	68	11	600	469	78
4	600	496	83	12	600	502	83
5	600	499	83	13	600	544	90
6	600	433	72	14	600	517	86
7	600	547	91	15	600	433	72
8	600	458	76				

On July 22 the fertilizers were applied. The cost of fertilizers, as computed from the Manila prices for 1916, and their composition (as determined by Doctor Deming, formerly of this college) are given.

TABLE II.—*Composition and cost of fertilizers.*

	Peso per kilo.
Lime	0.02
Dried blood, 14 per cent nitrogen	0.10
Sulphate of ammonia, 20 per cent nitrogen	0.23
Nitrate of soda, 15 per cent nitrogen	0.20
Sulphate of potash, 40 per cent potash (K_2O)	0.23
Double superphosphate, 20 per cent phosphoric acid (P_2O_5)	0.22

Table III shows the plan and the corresponding cost of fertilization per hectare.

[8] *Phil. Agr. & Forest.* (1915), 4, Nos. 5–6.

TABLE III.—*Rate of applications and cost of fertilizers per hectare.*

Plot.	Fertilizers.	Rate of application per hectare.	Cost of fertilizers and their application per hectare.
		Kilos.	*Pesos.*
1	Control		
2	Lime	1,000	20.28
3	Dried blood	320	34.10
4	Nitrate of soda	320	66.41
5	Sulphate of potash	320	75.96
6	Sulphate of ammonia	320	75.96
7	Sulphate of potash and double superphosphate	640	75.96
8	Sulphate of ammonia and sulphate of potash	640	144.58
9	Control		
10	Nitrate of soda and double superphosphate	640	134.80
11	Sulphate of ammonia and double superphosphate	640	144.36
12	Nitrate of soda and sulphate of ammonia	640	149.14
13	Sulphate of ammonia, sulphate of potash, double superphosphate, and nitrate of soda	1,000	280.41
14	Sulphate of potash, nitrate of soda, and double superphosphate	1,000	219.78
15	Sulphate of ammonia, sulphate of potash, and double superphosphate	1,000	216.78

Nitrate of soda at the rate of 320 kilograms per hectare was added to plot 13 two months after the first application.

The complete fertilizers were mixed according to the formula 8–6–8, that is to say, the ratio between the nitrogen, potash, and phosphoric acid was as 8:6:8.

The variety used in these experiments, according to a previous investigation by me, matures in about nine months. The canes were analyzed from March 5 to 16 and were harvested from March 13 to 22. The results of the analyses are shown in Table IV, and the field data are shown in Table V.

Table IV shows that the complete fertilizer plot (plot 14) with nitrogen in the form of nitrate of soda gave the highest purity in the juice; next comes plot 5, to which sulphate of potash alone was applied; and then follows plot 13, which was treated with complete fertilizers and given a subsequent application of nitrate of soda.

TABLE IV.—*Showing results of experiments with fertilized plots.*

Plot.	Juice (determined). Corrected brix.	Juice (determined). Sucrose.	Juice (determined). Purity.	Juice (determined). Invert sugar.	Bagasse (determined). Sucrose.	Bagasse (determined). Invert sugar.	Bagasse (determined). Fiber.	Cane (calculated). Sucrose.	Cane (calculated). Invert sugar.	Cane (calculated). Fiber.	Juice extraction by hand mill.	96° sugar from 100 tons of cane.	Quality of cane.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Tons.*	
1	15.47	12.64	81.70	1.13	7.08	0.14	32	10.90	0.82	10.13	68.8	9.82	1:10.2
2	15.68	13.11	83.60	0.95	7.26	0.03	35	11.25	0.65	11.01	68.4	10.26	1:9.8
3	16.15	13.86	85.82	0.70	8.76	0.07	27	12.16	0.49	9.20	66.6	11.25	1:8.9
4	14.68	11.96	81.60	1.34	7.60	0.16	34	10.68	0.92	10.00	70.5	9.60	1:10.2
5	16.22	14.52	89.52	0.49	8.05	0.04	26	12.43	0.34	8.82	67.8	11.72	1:8.5
6	15.55	12.68	81.54	1.31	6.73	0.13	36	10.90	0.95	9.15	70.2	9.81	1:10.2
7	16.24	13.79	84.29	0.76	13.21	0.08	34	13.61	0.55	10.45	69.8	12.50	1:8.0
8	14.87	12.08	81.30	0.83	11.42	0.10	39	11.90	0.61	11.33	70.3	10.70	1:9.9
9	15.82	13.08	82.68	0.98	6.66	0.11	35	11.34	0.75	10.08	73.0	10.30	1:9.7
10	14.73	11.68	79.29	1.30	6.96	0.15	40	10.12	0.85	11.73	70.0	9.00	1:11.0
11	12.50	9.82	78.56	1.67	4.25	0.19	32	8.21	1.24	8.96	71.2	7.24	1:14.0
12	17.30	14.97	86.53	1.64	8.96	0.12	34	13.10	1.16	10.61	69.0	12.15	1:8.2
13	18.86	16.48	87.38	0.72	12.05	0.09	39	15.22	0.64	12.16	71.7	14.21	1:7.0
14	19.72	17.78	90.16	0.53	9.95	0.06	38	15.22	0.37	12.20	67.4	14.48	1:6.9
15	17.82	15.12	84.90	0.89	9.43	0.08	29	13.32	0.47	9.48	68.4	12.25	1:8.0

TABLE V.—*Field data of sugar cane in fertilized plots.*

Plot.	Plot results. Stools two months after planting.	Stools at harvest.	Mortality at harvest.	Canes to the stool. Average.	Canes to the stool. Lowest.	Canes to the stool. Highest.	Cane measurements. Average diameter.	Cane measurements. Average height.	Cane measurements. Average weight of 100 canes.	Actual weight of canes at harvest.	Waste.	Hectare basis. Yield of cane.		Gain or loss over average of checks.
			P.ct.				*cm.*	*m.*	*Kilos.*	*Kilos.*	*P.ct.*	*Kilos.*	*Tons.*	
1	483	471	2	5	1	14	3.02	2.41	131.06	3,233	2	71,844.44	71.84	----------
2	472	470	0.4	6	1	13	3.12	2.25	120.27	3,535	2	78,555.55	78.55	+ 0.76
3	405	405	0	6	2	14	2.77	1.74	117.04	3,035	1	67,444.44	67.44	—10.33
4	497	441	9	7	1	18	3.04	2.38	121.26	3,889	3	86,422.22	86.42	+ 8.63
5	499	499	0	6	1	17	3.09	2.59	97.92	3,156	2	70,133.33	70.13	— 7.66
6	433	429	9	7	1	17	2.96	2.13	125.32	4,043	2	89,844.44	89.84	+12.05
7	547	547	0	6	1	19	3.05	2.51	125.77	4,128	3	91,733.33	91.73	+13.94
8	458	456	0.4	7	1	21	2.92	2.68	126.86	4,310	4	95,777.77	95.77	+17.98
9	507	507	0	7	1	18	2.56	2.51	103.80	3,769	1	83,755.55	83.75	----------
10	529	514	2	6	1	16	2.77	2.51	107.29	3,736	4	84,425.33	84.42	+ 6.94
11	469	467	0.4	7	1	20	3.50	2.69	128.07	4,288	3	95,288.88	95.28	+14.50
12	502	497	0.8	6	1	23	2.84	2.77	125.42	3,710	2.5	82,444.44	82.44	+ 4.65
13	544	543	0.1	6	1	18	3.24	2.72	123.66	4,142	2	92,044.44	92.04	+14.25
14	517	486	6	7	1	25	3.27	2.67	103.40	3,981	3	88,466.66	88.46	+10.85
15	433	395	0.9	7	1	22	3.14	2.48	106.93	3,861	2	85,800.00	85.80	+ 8.01

The combination of nitrate of soda with superphosphate (plot 10) and that of the latter with ammonium sulphate (plot 11) show the lowest purity. The plots with nitrate of soda (plot 4) and sulphate of ammonia (plot 6) are below the check plots 1 and 9 in purity. Plot 11 gave the lowest percentage of sucrose in the cane, while the two plots with complete fertilizers with nitrogen in the form of nitrate of soda show the highest sucrose content. With the exception of plots 8, 10, and 11, all of the fertilized plots show a higher percentage of sucrose than either check.

The effect of fertilizers on the purity of the juice and the sucrose content of the cane can be best understood with the aid of fig. 1, in which curve 1 represents purity and curve 2 sucrose content of the cane. It will be noticed with interest that the rise and fall of the purity is accompanied by a similar course of the percentage of sucrose in the cane, with the exception of

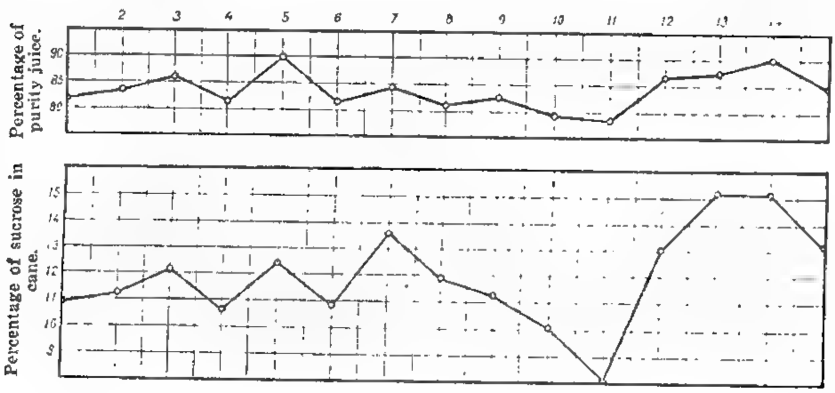

FIG. 1. *Curve 1*, effect of fertilizers on the purity of juice; *curve 2*, sucrose content of the cane.

plot 4, where the increase in purity is not accompanied by any increase in the sucrose content as compared with plot 13.

The effect of manuring on the saccharine content of the cane is a subject that up to the present time is not satisfactorily known. Eckart,[9] in Hawaii, found that unmanured cane was higher in purity than manured cane. Harrison and Bovel,[10] of Barbados, say that they have no definite information as to the specific effect of the different mineral constituents of fertilizers on the saccharine content of the cane. While Geerligs is in the same position, Deerr believes that cane manuring affects the tonnage of the cane rather than its saccharine content.

[9] Deerr, Noel, Cane Sugar (1911). [10] Ibid.

Table V indicates that the different fertilizers and combinations used had a varying effect on the yield of cane per hectare. Plots 3 and 5, the first fertilized with dried blood and the second with sulphate of potash alone, gave yields less than either check. The rest of the fertilized plots show an increase over the average yield of the controls. Plot 2 fertilized with lime alone and plot 12 fertilized with nitrate of soda and sulphate of ammonia are above plot 1 and below plot 9, which are the two control plots. All the others are above either control. These observations can be best understood with the aid of curve 1, fig. 2.

A table is given to show the relation between the yield of each plot in tons of cane and the yield calculated as 96° sugar per hectare. It is very interesting to note that while the plots

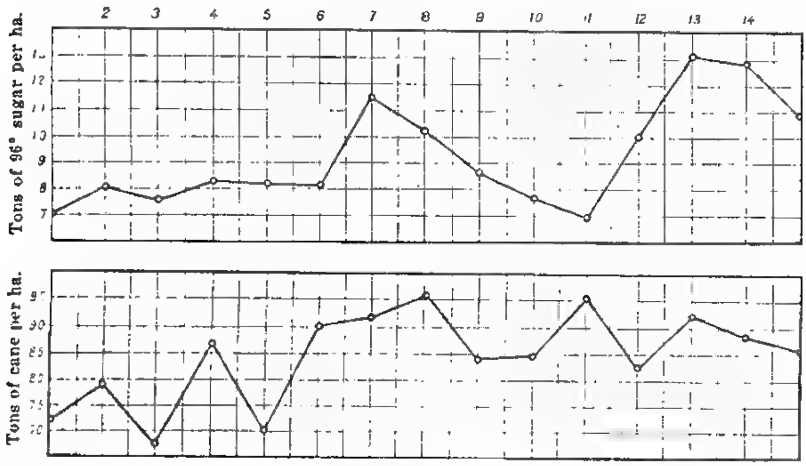

FIG. 2. *Curve 1*, effect of fertilizers on the yield of 96° sugar; *curve 2*, tonnage of cane per hectare.

from 1 to 6 and 9 to 11 show noticeable differences in the yield of cane per hectare, when compared as to their yield as 96° sugar, they show hardly any difference at all. Plots 7 and 8 show a decided increase over the control both in yield of cane and 96° sugar per hectare. While plot 12 is below control plot 9 in the yield of cane per hectare, it is above it in the yield of 96° sugar per hectare. Plots 13 and 14 gave almost the same yield of 96° sugar per hectare, and their yields are the highest obtained in these experiments. They are, however, below plots 8 and 11 in the yield of cane per hectare. Curve 2, fig. 2, shows the above observation plainly.

TABLE VI.—*Relation between yield of each plot in tons of cane and yield calculated as 96° sugar per hectare.*

Plot.	96° sugar from 100 tons cane.	Plot yield.		Hectare yield.		Gain or loss of sugar over average control.	Net price of sugar gained or lost per hectare.	Cost of fertilizing per hectare.	Gain or loss, due to application of fertilizers.
		Cane.	Sugar.	Cane.	Sugar.				
	Tons.	*Kilos.*	*Kilos.*	*Tons.*	*Tons.*	*Tons.*	*Pesos.*	*Pesos.*	*Pesos.*
1	9.82	3,233	317.48	71.84	7.05	0.0	0.0	0.0	0.0
2	10.27	3,535	363.04	78.55	8.06	0.22	33.44	20.28	13.16
3	11.25	3,035	341.50	67.44	7.59	—0.25	—38.00	34.10	—72.10
4	9.60	3,889	373.34	86.42	8.29	0.45	68.40	64.44	1.99
5	11.72	3,156	370.00	70.13	8.22	0.38	59.76	75.96	—16.20
6	9.81	4,043	397.00	89.84	8.20	0.36	55.00	75.96	—20.96
7	12.50	4,128	516.00	91.73	11.48	3.64	550.00	75.96	474.04
8	10.70	4,310	461.17	95.77	10.24	2.40	364.80	144.58	140.40
9	10.30	3,769	388.10	83.75	8.63	0.0	0.0	0.0	0.0
10	9.00	3,813	344.17	84.42	7.62	—0.22	—33.44	134.80	—168.24
11	7.24	4,288	313.00	95.29	6.90	—0.94	—143.00	144.36	—287.36
12	12.15	3,710	450.10	82.44	10.02	2.18	332.00	149.14	182.86
13	14.21	4,142	588.00	92.04	13.08	5.24	795.00	280.41	514.59
14	14.43	3,981	575.80	88.46	12.79	4.95	753.00	219.78	533.22
15	12.25	3,861	486.67	85.80	10.81	2.97	451.44	216.78	234.66

Table VI also shows which of the plots would produce the greatest returns. It is evident, judging from the results of these experiments, that the application of lime (plot 2), of a combination of sulphate of potash and double superphosphate (plot 7), of sulphate of ammonia and sulphate of potash (plot 8), of nitrate of soda and sulphate of ammonia (plot 12), of sulphate of ammonia, sulphate of potash, and double superphosphate with a subsequent application of nitrate of soda (plot 13), of sulphate of potash, nitrate of soda, and double superphosphate (plot 14), or of sulphate of ammonia, sulphate of potash, and double superphosphate (plot 15) will all more than pay for the cost of fertilizers and of their application. Plot 14 would give the highest return, although it is below plot 13 in the amount of 96° sugar that it would be possible to produce per hectare. This fact shows that it is better to use nitrate of soda at the very start than to use two forms of nitrogen in the combination. The superiority of nitrate of soda to sulphate of ammonia as a source of nitrogen for cane is indicated by a comparison of plots 13, 14, and 15.

CONCLUSIONS

1. Sulphate of potash alone and a complete fertilizer with nitrogen in the form of nitrate of soda gave the highest purity in the juice. Double superphosphate in combination with either

form of nitrogen lowered the purity of the juice to a large extent.

2. The effect of fertilizers on the percentage of sucrose in the cane runs parallel with that on the purity of the juice, although it is more pronounced in the latter than in the former.

3. Sulphate of ammonia in combination with sulphate of potash or with double superphosphate produced the greatest yield of cane. Dried blood and sulphate of potash apparently lowered the yield of cane.

4. Increased yield in tons of cane per hectare does not necessarily mean increased production of 96° sugar.

5. The complete fertilizer with nitrogen in the form of nitrate of soda would give the highest return in pesos and centavos if used on this soil.

6. It is not claimed that the results of these experiments will be directly applicable even at separated points near the college, and it is doubtful whether the same results would be obtained if the fertilizers used were tried on a different field in the college itself. However, it is concluded that the complete fertilizer with nitrogen in the form of nitrate of soda would in all probability give good results on an ordinary soil.

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